
WDM-PON Overview

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Introduction: why p-t-p network?

> Trends

- Bandwidth growth
 - 10 times every 5 years (Nielsen's law, Optical **Moore's** law)
- Video centric services
 - High, bandwidth, high QoS, long connection time
 - Picture and video clip exchange
- Convergence over fiber based optical networks
 - Voice, data, video, and wireless (2G , 3G, LTE)
 - Residential and business

> Observations

- Long lifetime of outside plant
 - Fiber and passive devices guarantee > 25 years lifetime.
- TDM-PON
 - Ever changing technology: BPON → GPON → 10 G PON → 40 G PON
 - Limited scalability due to high speed transmission over high loss link

WDM PON Values

> Future proof solution

- Future proof Lifetime Outside Plant operation (>25years)
- Graceful Upgrade Path to Future High Bandwidth Applications

> WDM-PON scales dedicated BW to 1 G, 10 G and beyond

> Improved Customer Experience

- Secure symmetric p-t-p connection, No bandwidth sharing
- Bit rate and protocol transparencies
- Easy protection and fault localization

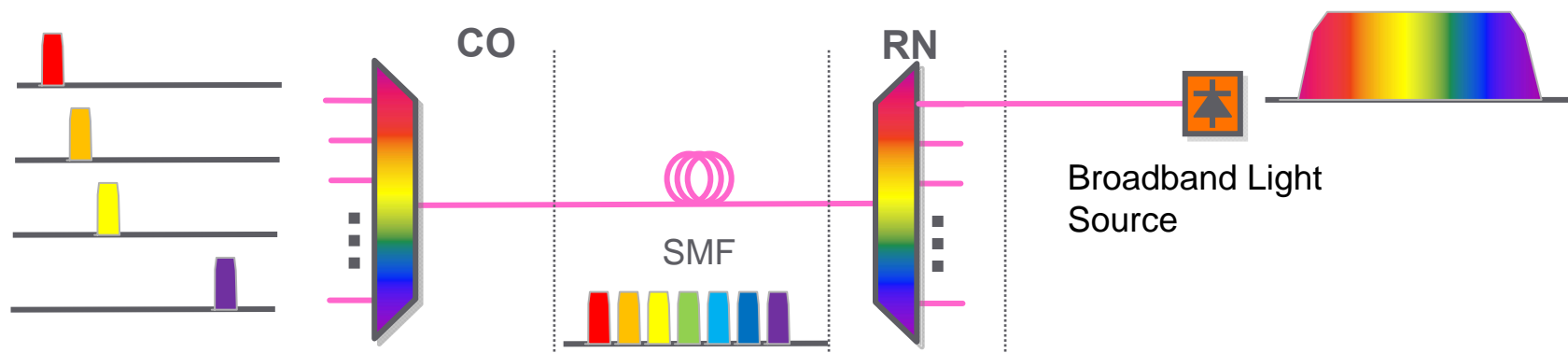
> Low Total Cost of Ownership

- Low OPEX cost effectively provided by colorless ONTs
- Low upgrade cost for future high bandwidth services
- One infrastructure for residential and business services
- Achieved inflection point for component industrialization start
- Significant improvements in WDM and DSP to improve reaches aiding in cost reduction

Colorless optical sources

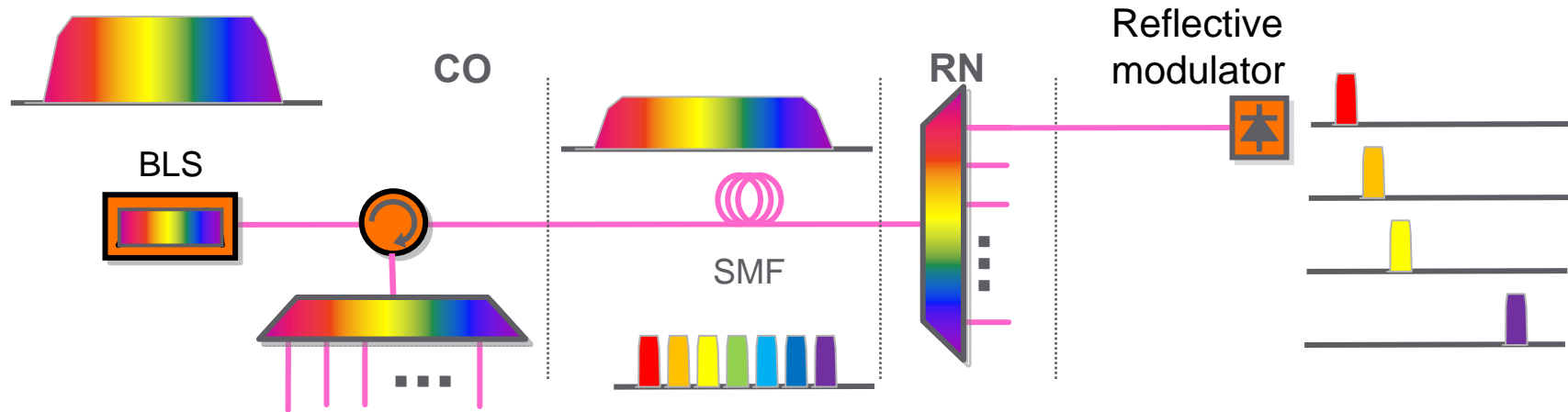
- > Colorless ONT (ONU) is essential for WDM-PON, since multiple users are connected to a PON.
- > Methods for colorless operation
 - Broadband light sources
 - A source that covers spectral range of transmission
 - Suffers slicing losses
 - Injection seeding
 - Injection of seed light from a CO to ONT
 - ONT has an reflective modulator
 - Requires seed light
 - Tunable lasers
 - A narrow band light tunable over spectral range of transmission
 - Needs prior information of wavelength

Broadband Light Sources



- A simple method
- Slicing loss $> 1/N$
- Limitation in modulation bandwidth for some sources
- Beat noises for an incoherent sources
 - . Beat noise can be mitigated with a low noise multi-wavelength laser (e.g., QD laser).

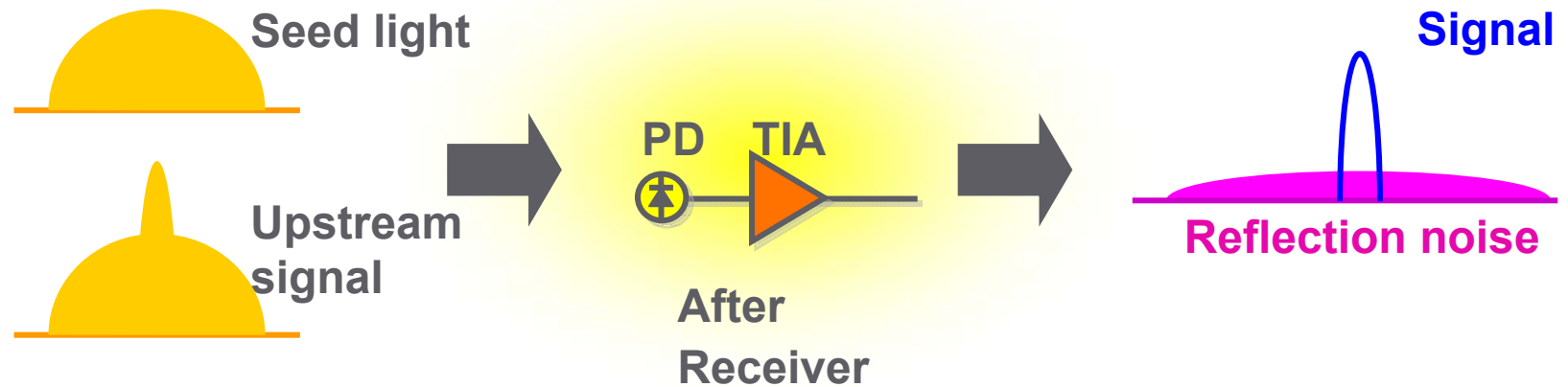
Injection seeded reflective modulators



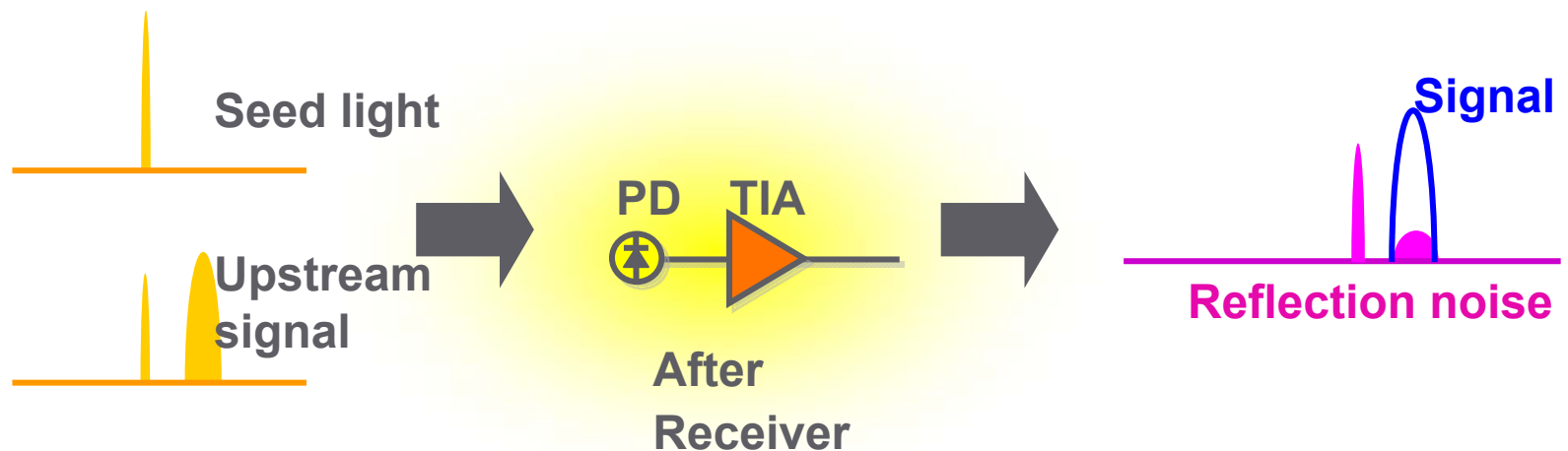
Seeding sources	Limiting factors	Reflective modulators
Incoherent light (ASE)	Source noise	F-P LD, RSOA, EA+SOA No restriction on spectral response
Coherent light (Bank of DFB LDs)	Reflection noises	RSOA, EA+SOA Restriction on spectral response
Downstream signal (incoherent or coherent)	Source noise/reflection noise Downstream penalty	Same as above

Reduction of Reflection Noises

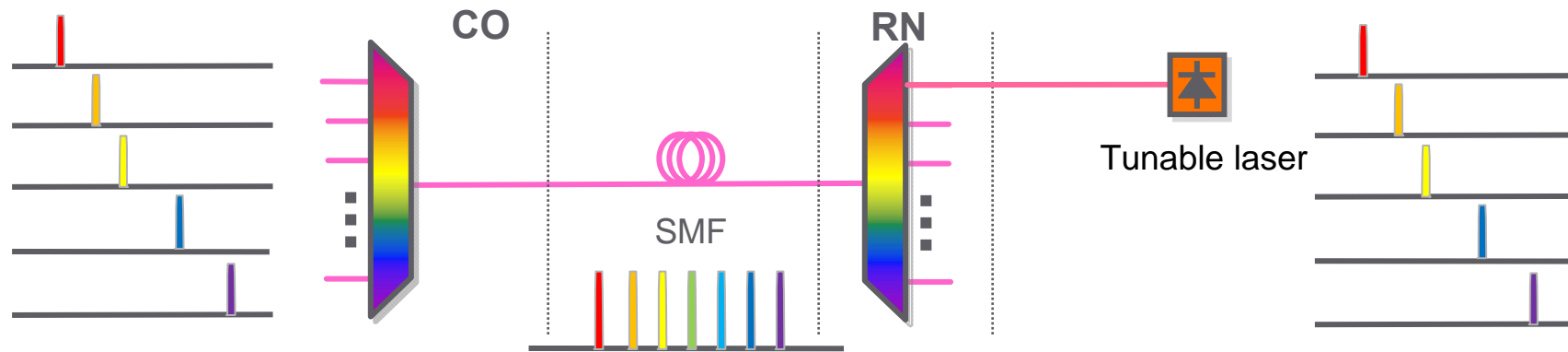
- > Broaden line-width of seed light
 - Broadband seed light, phase modulation, ...



- > Shift of signal spectrum

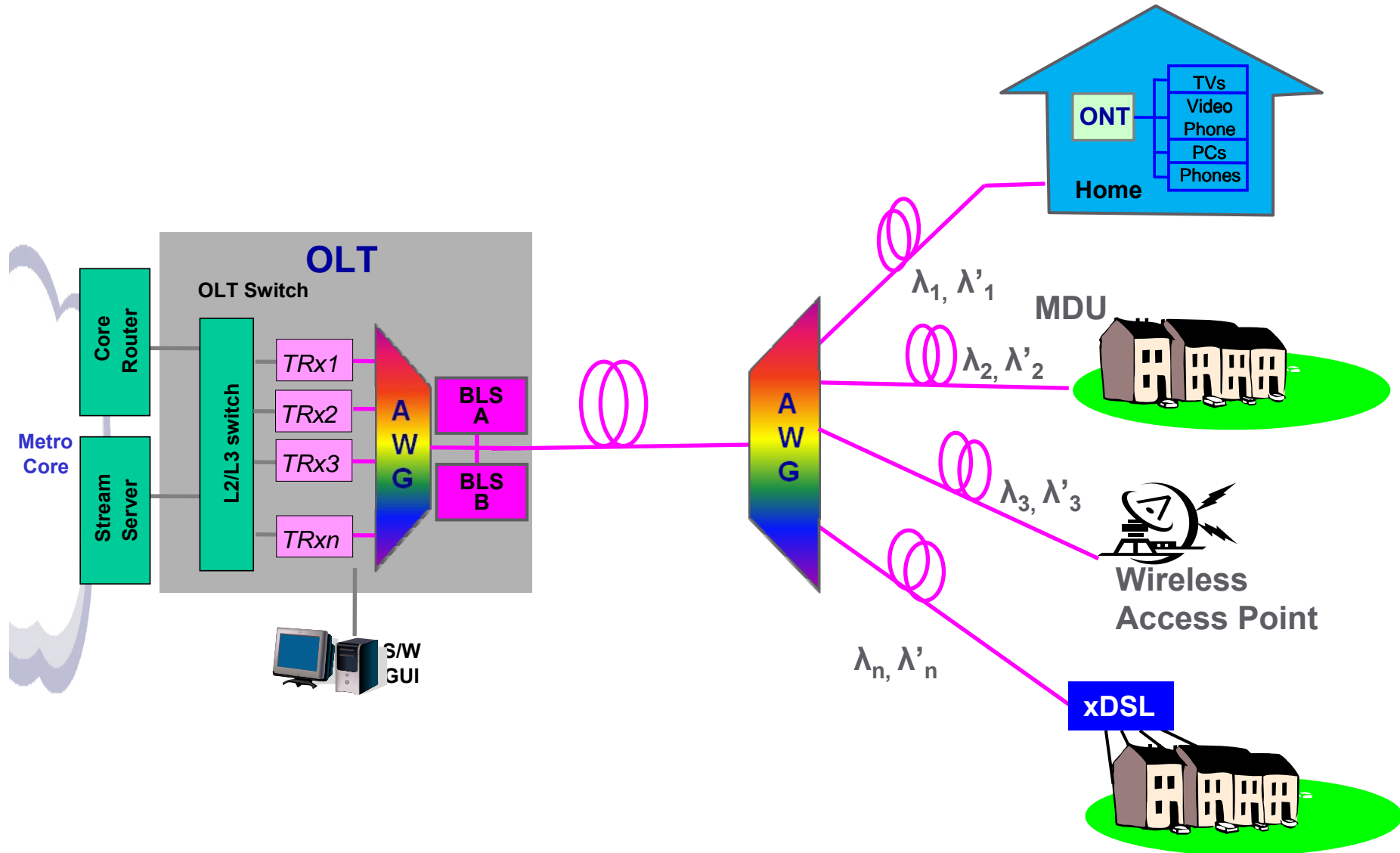


Tunable laser

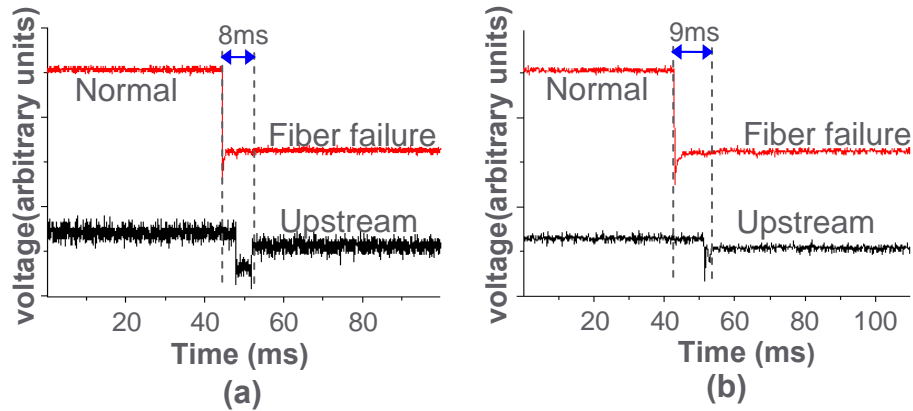


- No slicing loss
- Possibly high modulation bandwidth
- Low cost tunable lasers are the ultimate end goal.
- Coherent detection can improve link budget and channel counts.
 - . Needs coherent tunable laser and DSP
- Needs prior information for tuning wavelength
 - . End to end control may be complex to mitigate.
- Cost is very high for access applications.

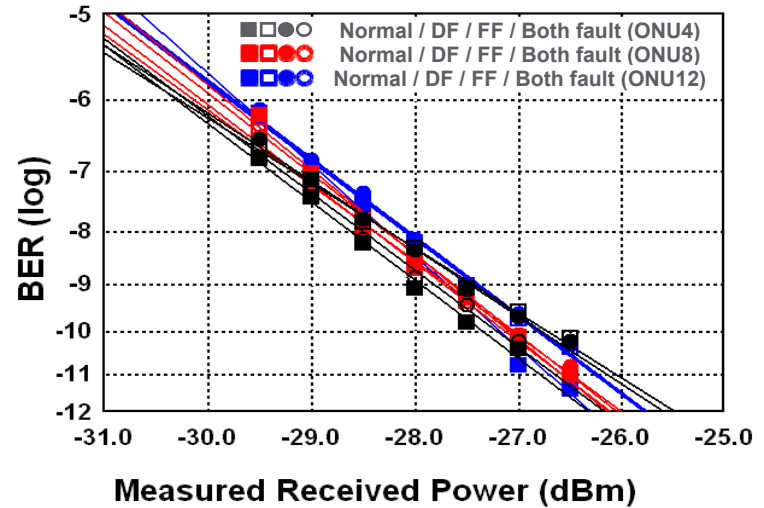
Architecture of WDM-PON



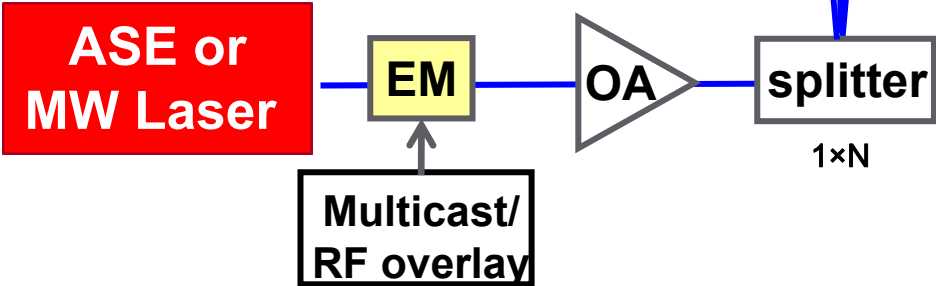
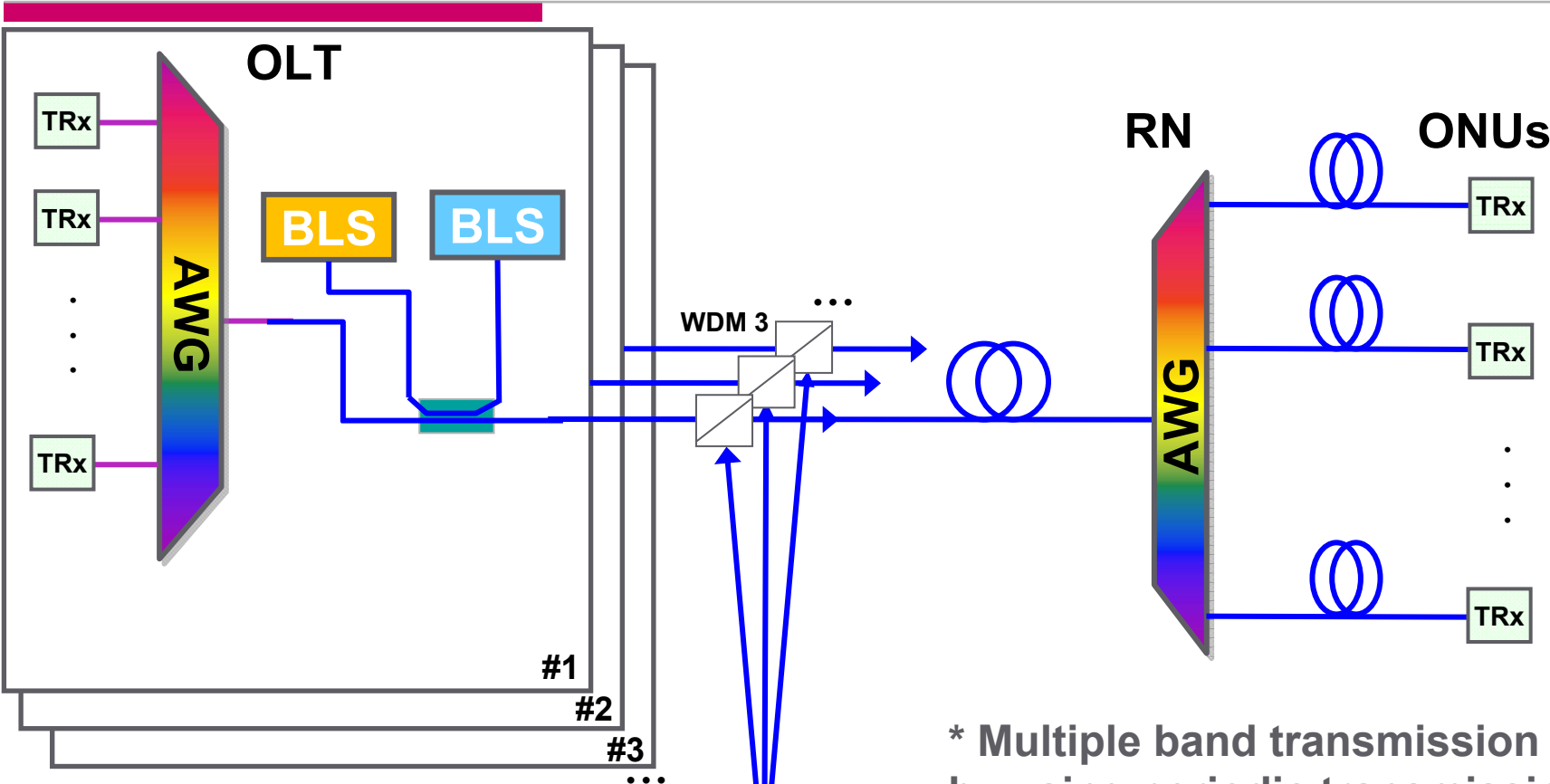
Protection of Fiber Faults



Switching Time



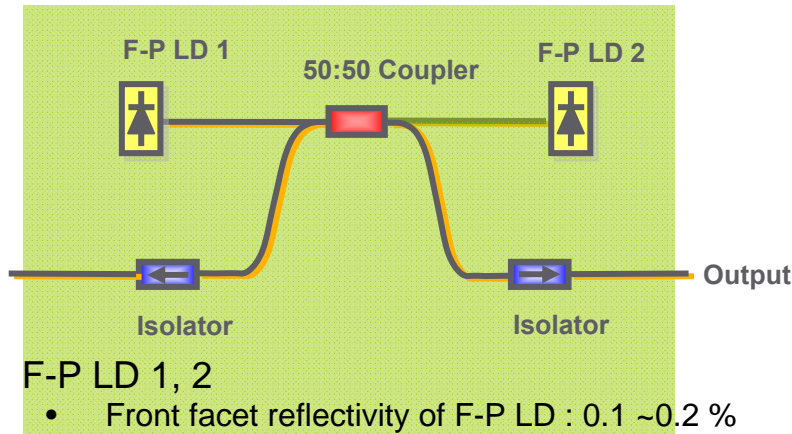
Broadcast/multicast in WDM-PON



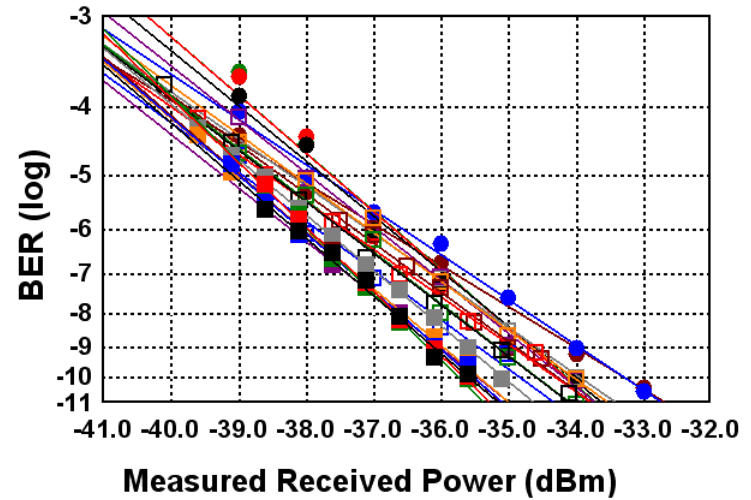
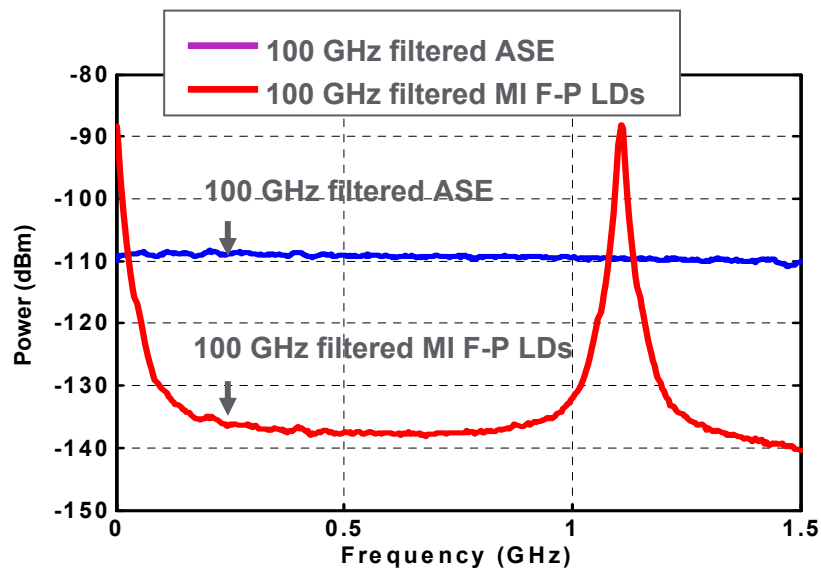
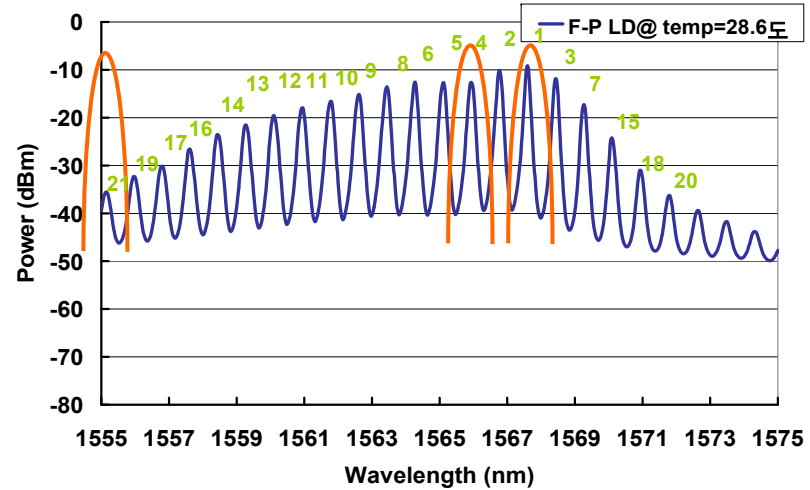
* Multiple band transmission by using periodic transmission characteristic of AWG

*EM (External modulator)
*OA (Optical amplifier)

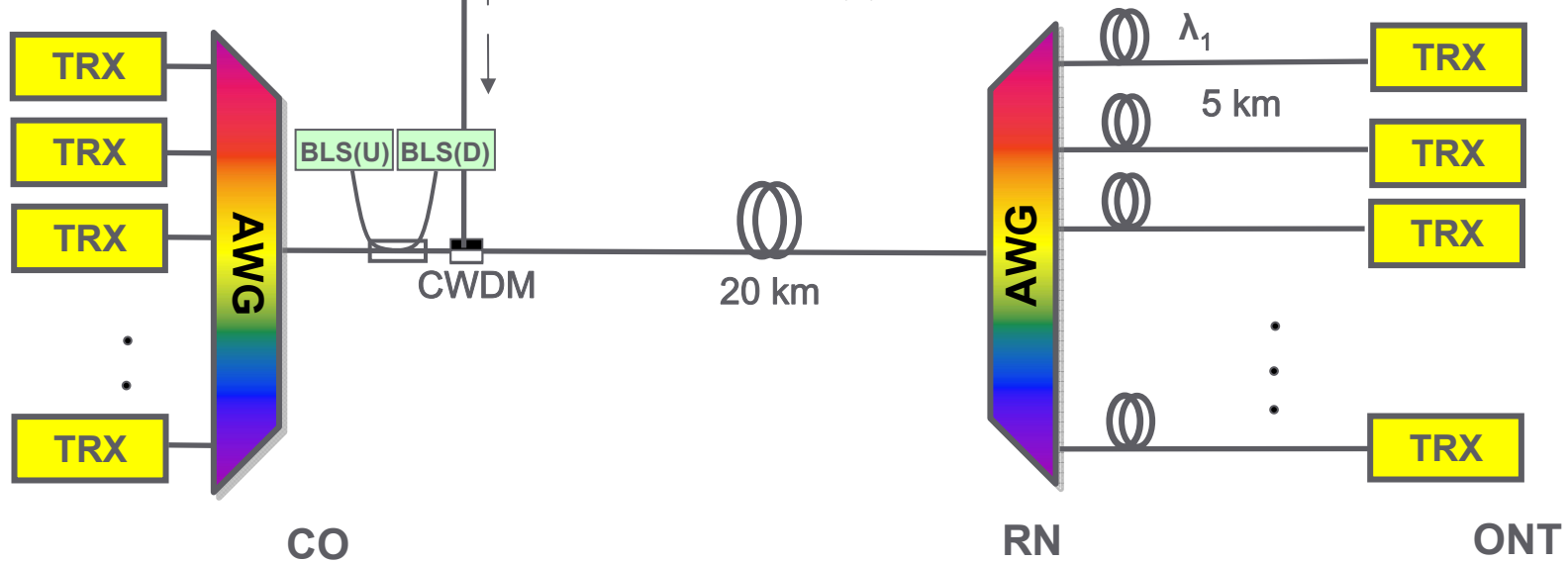
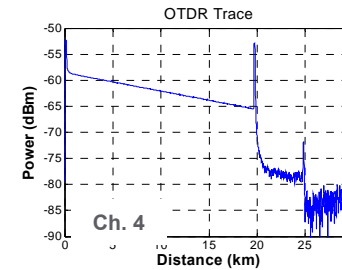
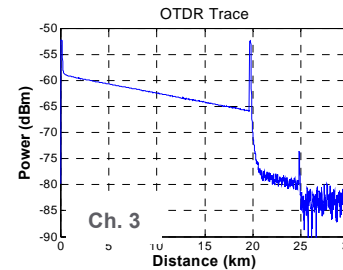
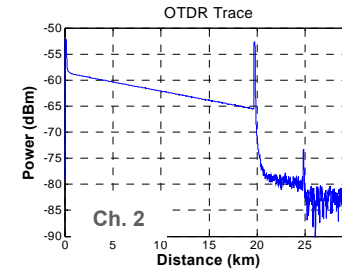
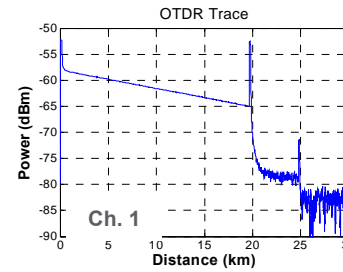
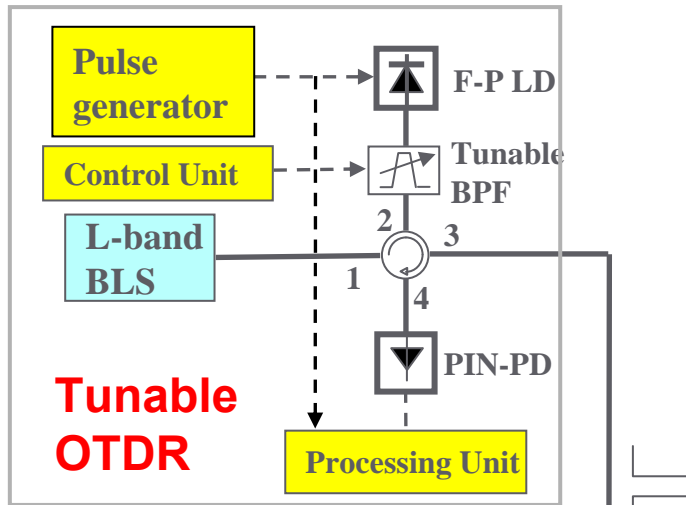
Broadcast signal transmission at 1.25 Gb/s channel



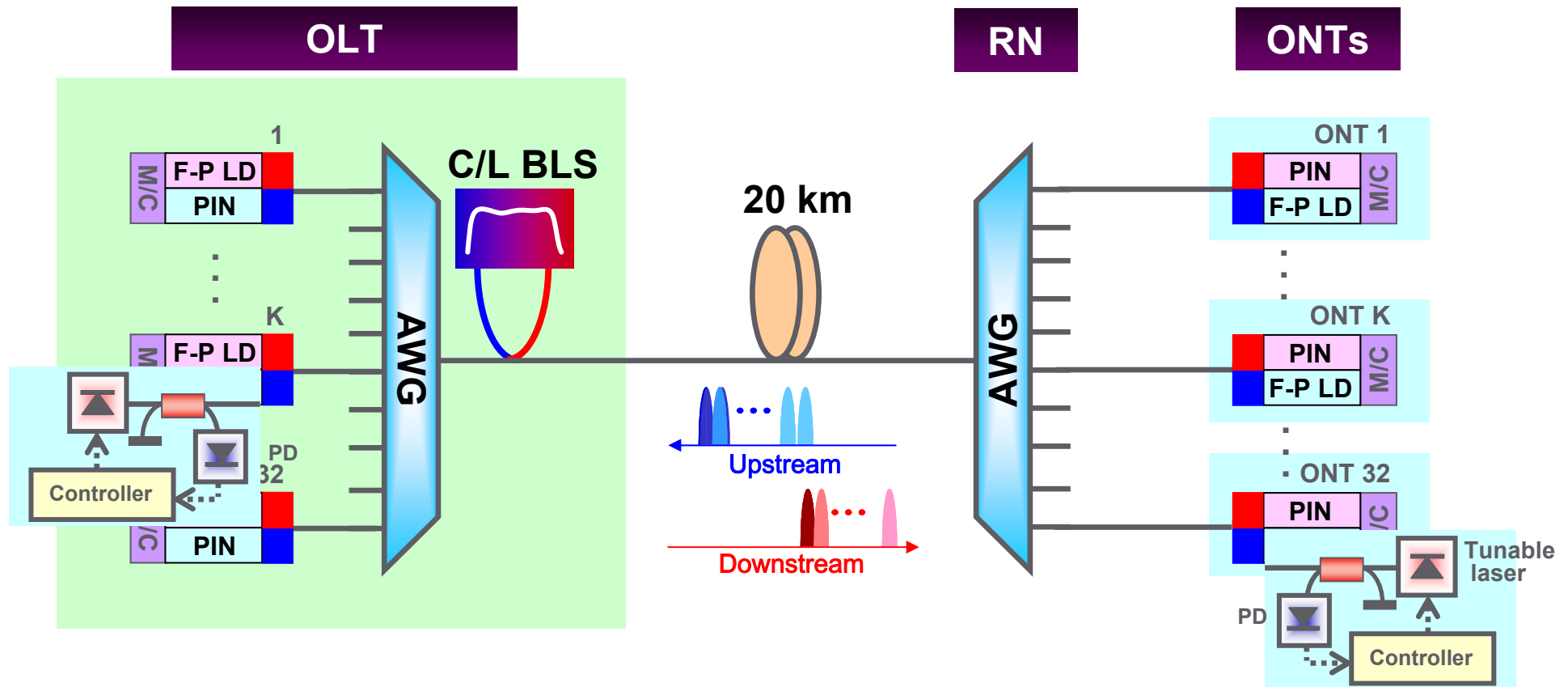
- > F-P LD 1, 2
 - Front facet reflectivity of F-P LD : 0.1 ~0.2 %
 - Laser cavity length : 400 μ m
- > Passive cavity length : 9 cm



Fault localization with tunable OTDR

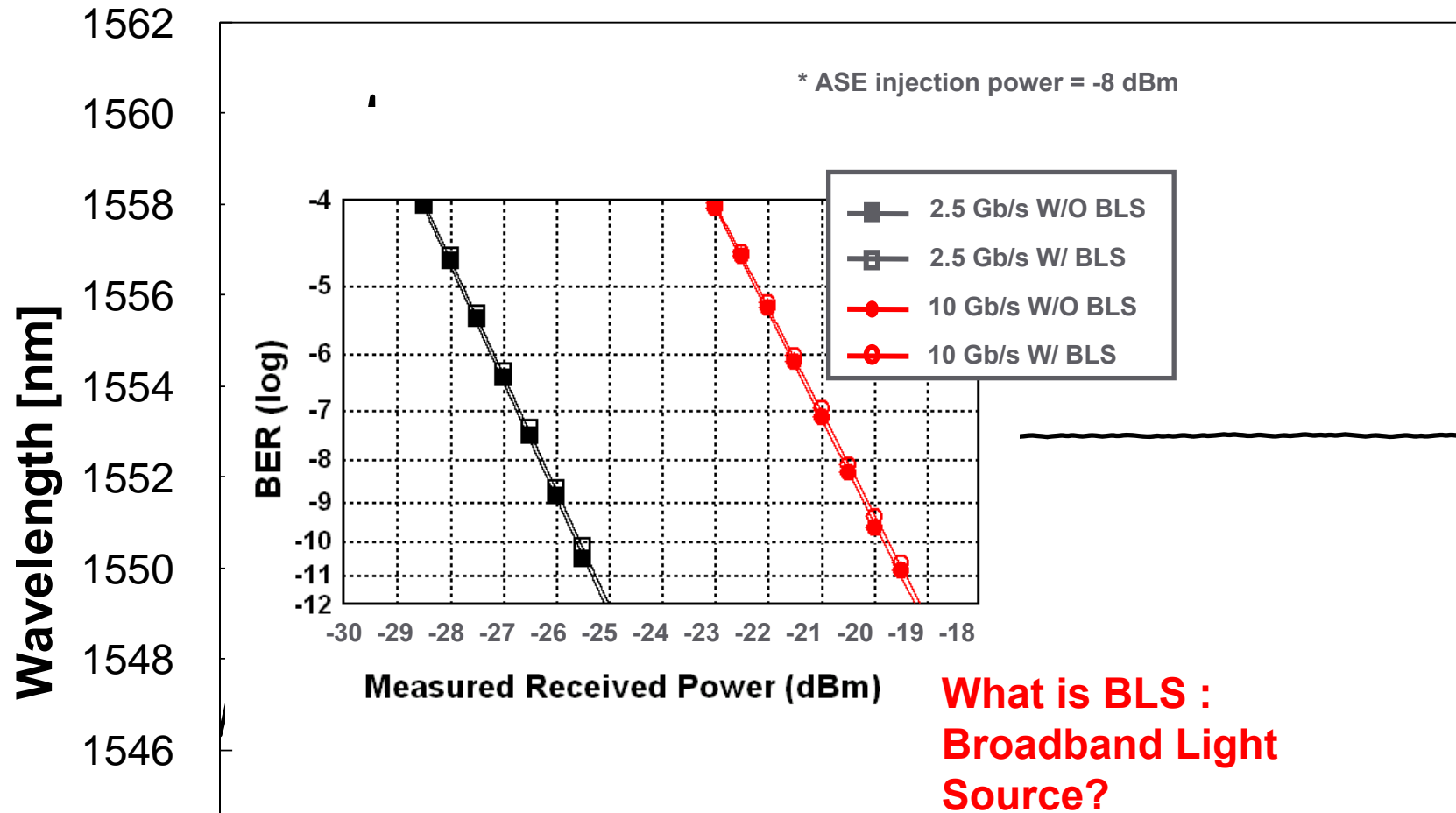


Upgrade to 10 Gb/s



Smooth migration is available to 10 Gb/s in WDM-PON based on the WL F-P LD by changing the transceivers both at OLT and ONT.

Self wavelength tracking



BLS induced penalty is negligible.

LONG Reach WDM-PON

> Passive long reach WDM-PON

- Fiber Raman amplifier
- Remote pumped EDFA
- Reduction of reflection noise is a major issue for injection seeding method.

> Skipping CO with simple active elements

- Seeding sources
- Optical amplifiers
- Hybrid WDM/TDM-PON
 - Increases split ratio up to ~1,000
 - Solves fiber bottleneck in metro section
 - Limited guaranteed bandwidth per user
 - Requires high bit rate transmission TDM-PON

Devices for WDM-PON

> Broadband light sources

- Amplified spontaneous emission
 - Semiconductor based (direct modulation): LED, SLD, ...
 - Doped fiber based (external modulation): EDFA, PDFA,
- Multi-wavelength laser (e.g. QD laser)
 - Low noise
 - Direct modulation capability is desired.

> Reflective modulators

- F-P LD or RSOA
- Electro-absorption modulator integrated with SOA

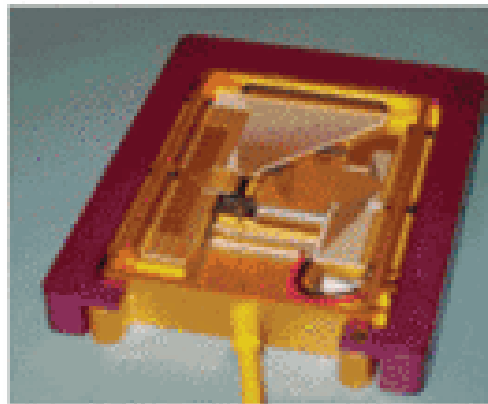
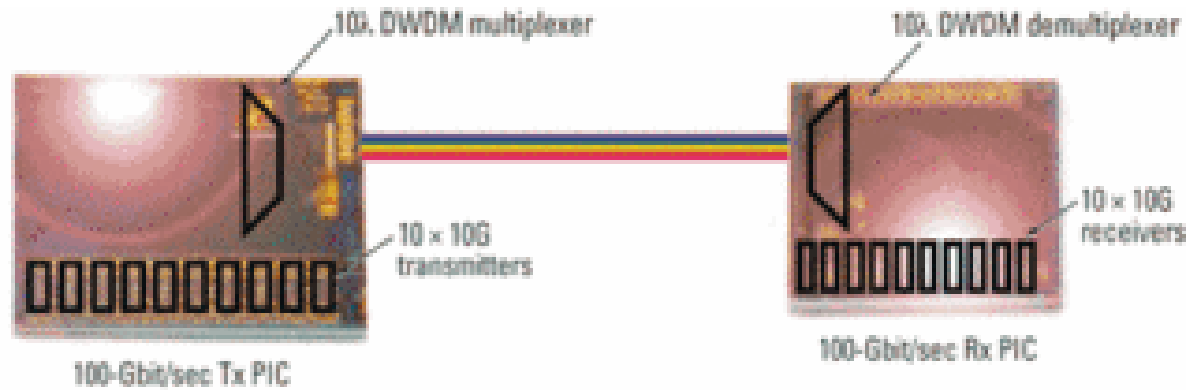
> Tunable laser

- Multi-section DFB/DBR laser, VCSEL
- PLC type tunable laser

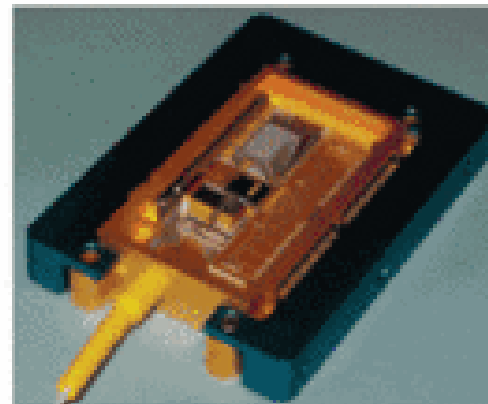
> Athermal AWG

- Periodic transmission characteristics

High density OLT



100-Gbit/sec Tx module



100-Gbit/sec Rx module

Source: Infinera

Source : Infinera

WDM-PON – Global Status

- > WDM-PONs based on injection seeded BLS were commercialized.
- > Global deployment underway
 - Successful commercial deployment in Korea and Europe
 - Several Lab, field trials & FOA in US, Canada, Japan, Taiwan
- > 125 Mb/s per channel systems:
 - 32 channels, 40 km reach capable today
 - Residential and Business users
 - Qualified and deployed in KT network since 2005: 200K users
- > 1.25 Gb/s per channel:
 - 16 channels, 20 km reach available today.
 - 32 channels system (40 Gb/s) in near future
 - Fully colorless operation; High immunity on optical back reflection

WDM-PON vs. TDM-PON

Multiple access (upstream)	WDMA	TDMA
Downstream	WDM	TDM
Guaranteed BW	Line rate	Line rate / N (BW sharing)
Burst mode	No	OLT and ONT
Statistical gain	No	Yes
Splitting loss [dB]	3 – 5 dB (WDM filter loss)	16 - 17 dB (1 x 32 splitter)
SNR penalty	No	$N^4 \sim N^5$
Bit rate transparency	Unlimited	~ 10 Gb/s
Protocol transparency	Yes	No
Open architecture and unbundling support	Easy	Difficult
Fault localization (OTDR)	Easy	Difficult
Key technologies	- Color free optical source	- High speed transmission - Burst mode receiver

Summary

- > Bandwidth Demands are growing (witness this activity)
 - Engage now to address current and emerging network requirements
- > WDM-PON is one of the lead candidates for NGA2
- > WDM-PON technology ready for deployment now
 - Provides future proof OSP and low TCO
 - Components are available now to build systems
 - IEEE Standard Ethernet protocol and industry accepted OAM
 - Complementary to NGA1 and new green field applications